An Integrated Gate Turnaround Management Concept Leveraging Big Data/Analytics for NAS Performance Improvements

William Chung,[1] Girish Chachad,[2] and Ronald Hochstetler[3]
SAIC, Moffett Field, California, 94035

The Integrated Gate Turnaround Management (IGTM) concept was developed to improve the gate turnaround performance at the airport by leveraging relevant historical data to support optimization of airport gate operations, which include: taxi to the gate, gate services, push back, taxi to the runway, and takeoff, based on available resources, constraints, and uncertainties. By analyzing events of gate operations, primary performance dependent attributes of these events were identified for the historical data analysis such that performance models can be developed based on uncertainties to support descriptive, predictive, and prescriptive functions. A system architecture was developed to examine system requirements in support of such a concept. An IGTM prototype was developed to demonstrate the concept using a distributed network and collaborative decision tools for stakeholders to meet on time pushback performance under uncertainties.

I. Introduction

Gate Turnaround Performance Management, i.e., aircraft arrival at the gate, off-loading, servicing, reloading of passengers, baggage and cargo, door-closing, and pushback (referred to as Gate Turnaround), plays a key role in the National Airspace System (NAS) gate-to-gate performance by receiving aircraft when they reach their destination airport, and delivering aircraft into the NAS upon pushback from the gate and subsequent takeoff. The time the aircraft spends at the gate in preparation to meet the planned departure time is influenced by many factors; and some having considerable uncertainties. Principal factors affecting gate turnaround include: weather, early or late aircraft arrivals, time spent disembarking/boarding passengers, unloading/reloading cargo, aircraft logistics/maintenance services, ground handling, traffic density on the ramp, availability of movement areas for taxi-in and taxi-out, deicing, and departure queue management for takeoff. Missing the scheduled pushback time can produce a delayed departure that can cause sufficient schedule deviation to potentially cause a schedule disturbance throughout the flight. Large delays can ripple into an airline operator's schedule for other aircraft in their fleet.

In contrast to its importance, the gate turnaround process is not managed well in today's operations and does not effectively make use of technologies that provide enhanced data and modeling of gate operations. Gate Turnaround requires multiple participants, who may not be under a single jurisdiction. Gate turnaround, i.e., door closing time, falls under individual airlines' responsibility, and is managed by multiple organizations within the airline. Gate pushback, on the other hand, is under the responsibility of either a Ramp or Ground controller. There is no coordination on pushback times between the airlines and ground control. Gate arrival and departure times are not fully integrated with surface and terminal area NAS automation and frequently take place in an ad-hoc, first-come-first-served manner.

To address these issues, NASA's Spot and Runway Departure Advisory (SARDA)[1] has been developing tower controller advisory tools to improve the flow of surface traffic. Additional work has been done to applying machine learning techniques in taxi-out time prediction[2] to improve the takeoff time performance. FAA has also identified Traffic Flow Data Manager (TFDM)[3] to provide better predictive and collaborative decision-support tools to the stakeholders such that more informed tactical decisions can be made to improve the surface traffic under

[1] Chief Aerospace Engineer, Training and Simulation, NASA Mail Stop 243-6, Moffett Field, CA, Senior Member.
[2] Principal Systems Engineer, Training and Simulation, NASA Mail Stop 243-6, Moffett Field, CA, Member.
[3] Senior Aerospace Engineer, Training and Simulation, Fort McNair, DC, Senior Member.

uncertainties. The Big Data/Analytics technologies[4] could offer additional benefits by providing predictive models extracted from historical data according to specific set of uncertainty parameters, which are potentially well suited for the complicated gate turnaround environment.

The Integrated Gate Turnaround Management (IGTM) concept was developed under the NASA "Big Data Analytics, and Net-enabled ATM and Airspace Operations Project" to identify air traffic management (ATM) functions that can benefit from networked, net-enabled, and/or cloud-based architecture. The project team assembled to tackle this challenge included subject matter experts in ATM, airline operations, airport operations, and in big data management architectures.

The IGTM concept is therefore focused on the NAS performance in an integrated service space at an airport terminal or terminals by leveraging following technologies to improve the traffic throughput performance at the gate in meeting the on time performance:

1) Data analytics technologies with multiple historical databases and live data to establish bounds of uncertainties of dependent parameters associated with NAS performance,[4,5,6]
2) A distributed data network shared by stakeholders,[7]
3) Collaborative decision tools,[8,9] for stakeholders to optimize the arrival and departure performance at an airport through en route, terminal, and the gate.

II. Concept of Operations (CONOPS) for the IGTM

The IGTM concept is developed based on the methodology shown in Figure 1. By analyzing historical data and identifying the dependency of uncertainties in NAS performance parameters or patterns, the adaptive analytics will develop performance models as functions of independent parameters, such as: weather, traffic density, time of the day, day of the week or year, type of airplane, and origin and/or destination of the flight. With these models, IGTM can develop descriptive, predictive, and prescriptive information for a given flight's service performance based on the current states of the NAS, either nominal or off-nominal, and deliver scheduled, estimated (or predicted), and current (or actual) status of all flights within the IGTM's operational space at a given airport to all stakeholders via a user interface. These stakeholders include Air Traffic Control (ATC) ground controllers, ramp controllers, airport operators, and airline personnel, which includes dispatchers, flight and cabin crews, gate agents, and those responsible for fueling, catering, baggage/cargo handling, maintenance, and aircraft parking and pushback. The adaptive analytics analysis will continuously check the patterns developed from the historical data and compare with the live data, then make adjustments if significant deviation in the trend is developed from the process.

IGTM will also provide collaborative decision tools by applying the performance models to allow stakeholders to enhance NAS performance collaboratively through efficient surface movement, gate turnaround, and pushback under the nominal and off-nominal operational conditions. To maximize the IGTM's benefits, integration with the

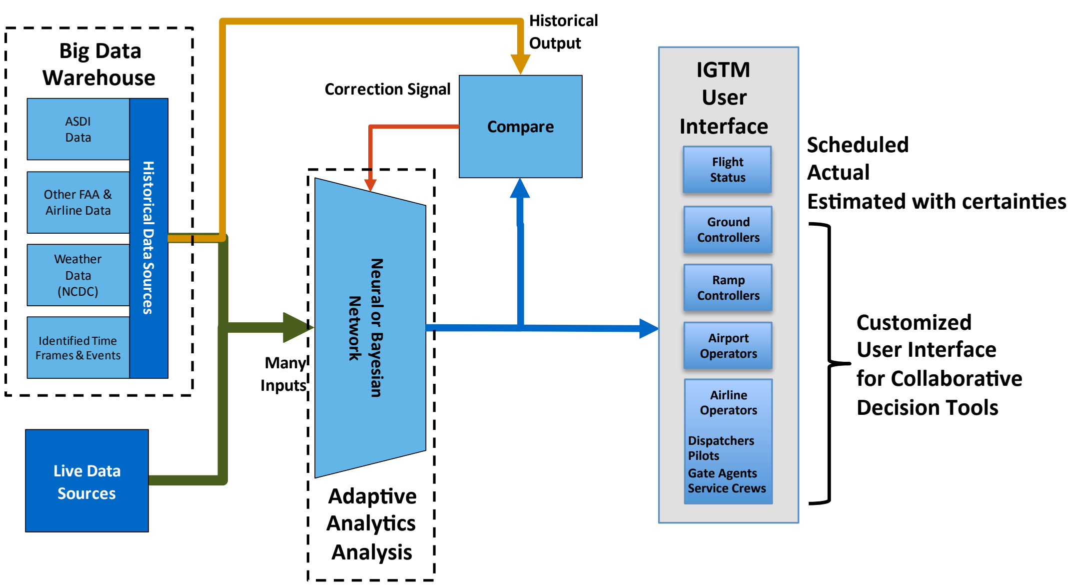

Figure 1. An Integrated Gate Turnaround Management methodology

en route and terminal automation tools, such as Traffic Flow Management System (TFMS),[10] Terminal Flight Data Manager (TFDM),[3] and Center TRACON Automation System (CTAS)[11] as well as surface sequencing optimization tool such as the NASA developed Spot and Runway Departure Advisor (SARDA)[1] is expected.

A. Predict System Status with Uncertainties

The IGTM provides a unified picture of the schedule status of each aircraft and all of the processes and support functions that are required for the flights to depart on schedule. This tracking begins while the aircraft is en route with an estimation of its ability to meet its scheduled time from the top of descent. At the same time, the system tracks the schedule performance of each element of the airport facilities that are required for on-time gate turn around and takeoff of the aircraft. These factors include:

- Geography of the airport surface
- Projected roll-out and taxi time
- Traffic congestion at the in-bound spot
- Availability of the gate (i.e., is the previous flight leaving on schedule?)
- Availability of the baggage/cargo unloading crew
- Availability of the baggage/cargo loading crew and the baggage/cargo itself
- Catering service availability
- Fueling service availability
- Availability of technicians and materials for any anticipated maintenance
- Deicing service availability
- Snow plowing service availability
- Projected out-bound taxi time

The IGTM will use live data and historical performance models from the Big Data/Analytics, Figure 1, under similar conditions to forecast the times of aircraft touchdown, arrival at the in-bound spot, arrival at the gate, gate pushback, arrival at the outbound spot, and takeoff. It also provides a detailed snapshot of expected schedule performance of each operation involved in gate turn around.

In order to accomplish its mission, the IGTM uses a combination of information including detailed geography of the airport surface, characteristics of various aircraft models, actual and planned passenger, baggage, and fuel loads, assignments of gates, aircraft crews, and ground facilities along with schedule and current performance of with respect to the schedule. In addition, the IGTM collects performance data over time building a model of the average performance of various entities. This historical information allows the IGTM to more accurately estimate schedule performance of each flight as a function of the aircraft, ambient conditions, and required services. Each airline user has a detailed operational view of the schedules affecting each of its aircraft. Ramp controllers, service providers, and other aircraft operators see a summary view that protects proprietary information but provides summary schedule information that enables each stakeholder to plan for smooth operations.

B. Network Communications

IGTM requires data content and/or message exchanges among NAS and non-NAS operational services as well as collaborative decision communications among the stakeholders. Figure 2 presents notional system architecture for sharing IGTM information among NAS and non-NAS stakeholders. Communications under the System-Wide Information Management (SWIM)[7] and data messaging exchange will be an ideal application to support the IGTM communication functions. This diagram depicts the programs-of-record that produce/publish information for stakeholder consumption, historical data sources, stakeholders, and interface for IGTM value-added services (i.e. user-interface).

It should be noted that it is assumed that Enterprise Service Buses (ESBs)/Interfaces are in place to consume and/or produce information for a particular stakeholder domain (Airline, Airport, etc.). Consumed content is securely accessed, filtered per stakeholder requirements, and distributed within that stakeholder domain as determined by stakeholder operations. Again, the method of access will be determined by whether the information source or stakeholder is considered internal to NAS operations or external.

C. Collaborative Decision Tools

The IGTM will provide collaborative decision tools to allow stakeholders to manage nominal and off-nominal events with inherent uncertainties, such as late or early arrival, adverse weather conditions (e.g., limited visibility and thunderstorm, runway condition due to rain, snow, and/or ice), congestion at the surface, and

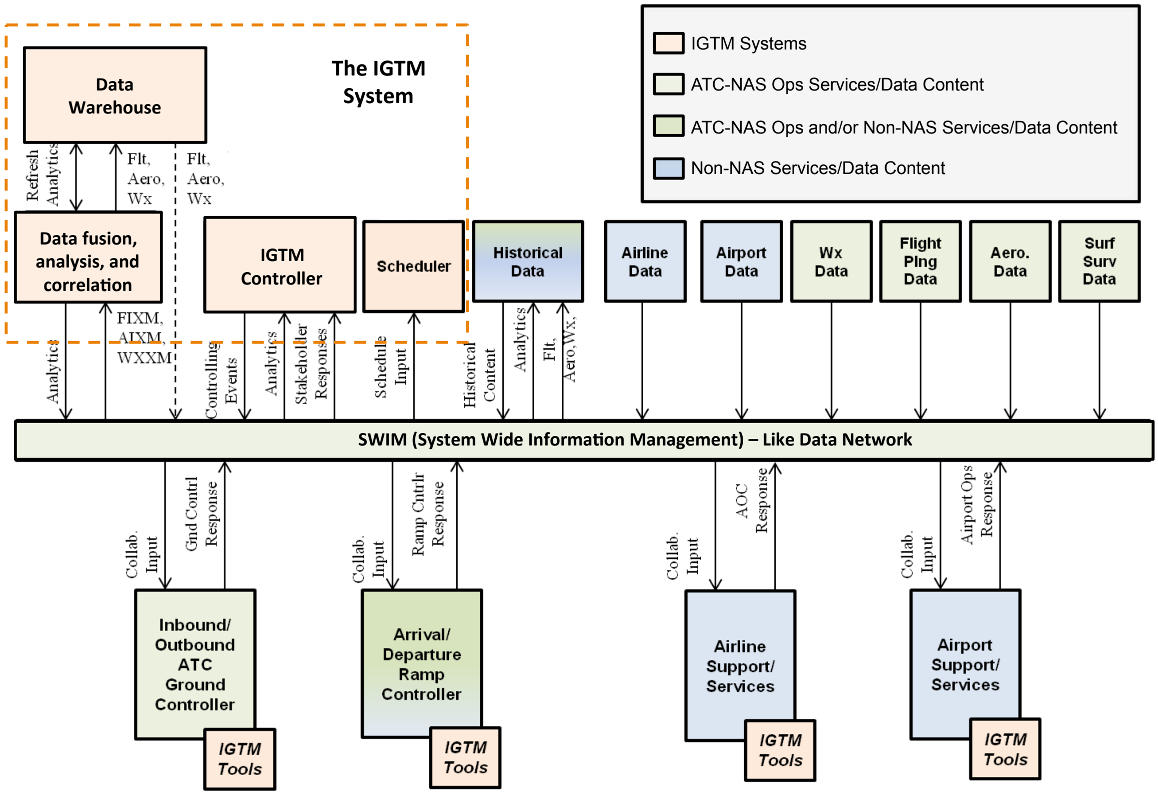

Figure 2. A notational IGTM system architecture

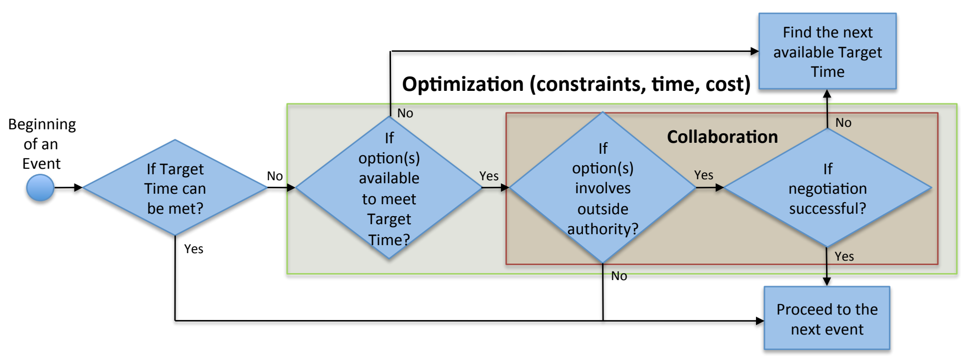

Figure 3. A notional Collaborative Decision Making (CDM) process

flight/cabin/ground crew availability. A notional decision tree is shown in Figure 3. The collaborative decision tools will allow stakeholders to collectively examine available options and resources in order to deal with operational issues, such as mitigating gate conflicts upon arrival, achieving an optimal pushback time upon departure, and optimizing the departure queuing sequence by utilizing descriptive, predictive, and prescriptive information from the Big Data/Analytics. In short, the tool will enable stakeholders to better meet the scheduled or planned time of arrival and departure, or, if need be, to delay or cancel a flight.

III. The IGTM System's Requirements

The IGTM must first evaluate current gate-turnaround operations and identify the primary independent parameters and their uncertainties that have impact on the NAS performance according to a given ATC ConOps on the surface and airlines' operational procedures at the airport terminal. The IGTM then identifies information resources that can be leveraged from Big Data and/or Net-enabled ATM data, and utilize analytics to develop performance models based on statistically significant patterns. With these performance models, descriptive, predictive, and prescriptive information about the current state of the NAS can be delivered to stakeholders. Thereby improving predictability to addressing uncertainties in a coordinated decision making process leading to improved NAS performance.

As shown in Figure 1, the Big Data/Analytics hosts the big data warehouse, reads in live ATM data, executes analytics analysis (adaptively) according to scenarios, and generate and deliver statistical performance data to the IGTM module. The Big Data/Analytics software needs to process large volumes of live data, which include flight tracks, ground tracks, schedule changes, weather, and runway configuration changes, and deliver the results with minimum latency. Industry has shown a data processing performance of 12 million messages per second with results returned in 120 msec.[6] It is yet to be determined if this level of data processing performance is sufficient to support the mass live and historical data analysis in the IGTM application.

Inputs to the Big Data/Analytics:

1) Historical data, which includes flight plans, performance data (delays at arrival), and weather data
2) Performance parameter query from the IGTM Outputs of the Big Data/Analytics
3) Statistical performance of queried performance parameters
4) Live data sources, which include traffic, flight plans, and weather

A. Systems Engineering Approach

A systems engineering approach was developed to identify independent parameters and functional requirements according to the IGTM system architecture. Figures 4-6 show the operational research approach in identifying the events and activities required during the approach, at the gate, and upon the departure at an airport respectively. Table 1 shows a further breakdown to independent parameters associated with representative events to be managed within the IGTM operational space. These events and independent parameters will define requirements for: Big Data, Analytics, collaborative decision tools, and network communications to support the IGTM concept for the gate operations.

B. Data Sources

The IGTM products and decision tools rely on data fusion from historical data and live data as shown in Figure 1. Representative historical data sources available from NASA's ATM data warehouse[12] for ATC-NAS services are listed in Table 2. Data for non-NAS services specifically related to airplane turnaround performance at the gate, such

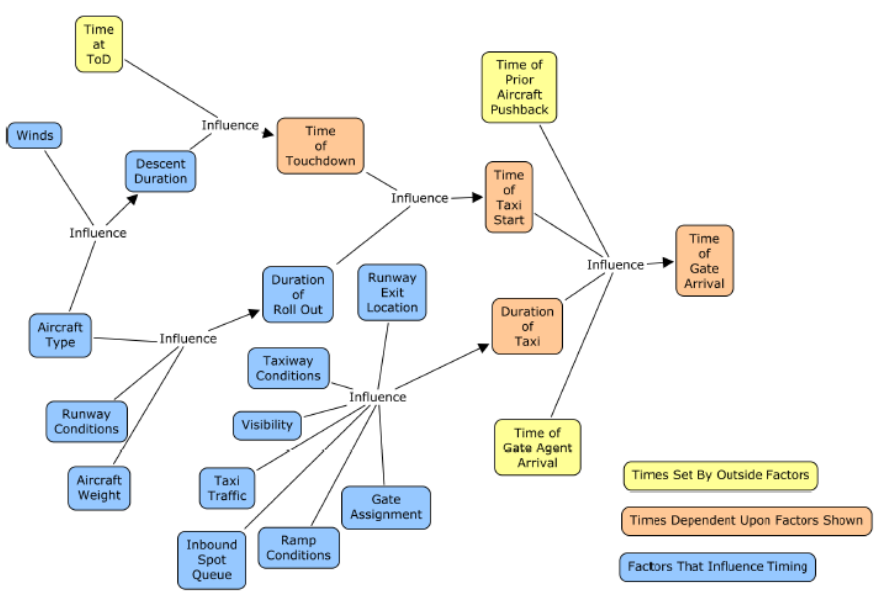

Figure 4. Flow of events for arrival flights

as: passenger deplaning rate, passenger boarding rate, cabin service time, catering service time, fueling time, baggage/cargo unloading rate, baggage/cargo loading rate, maintenance time per type of services, flight/cabin crew availability rate, and ground crew availability rate, will be needed from airlines. Additional non-NAS services data will be needed from airport operators. These include data for runway configurations, runway construction, snow plowing rate, and anti-icing facilities and processing rate.

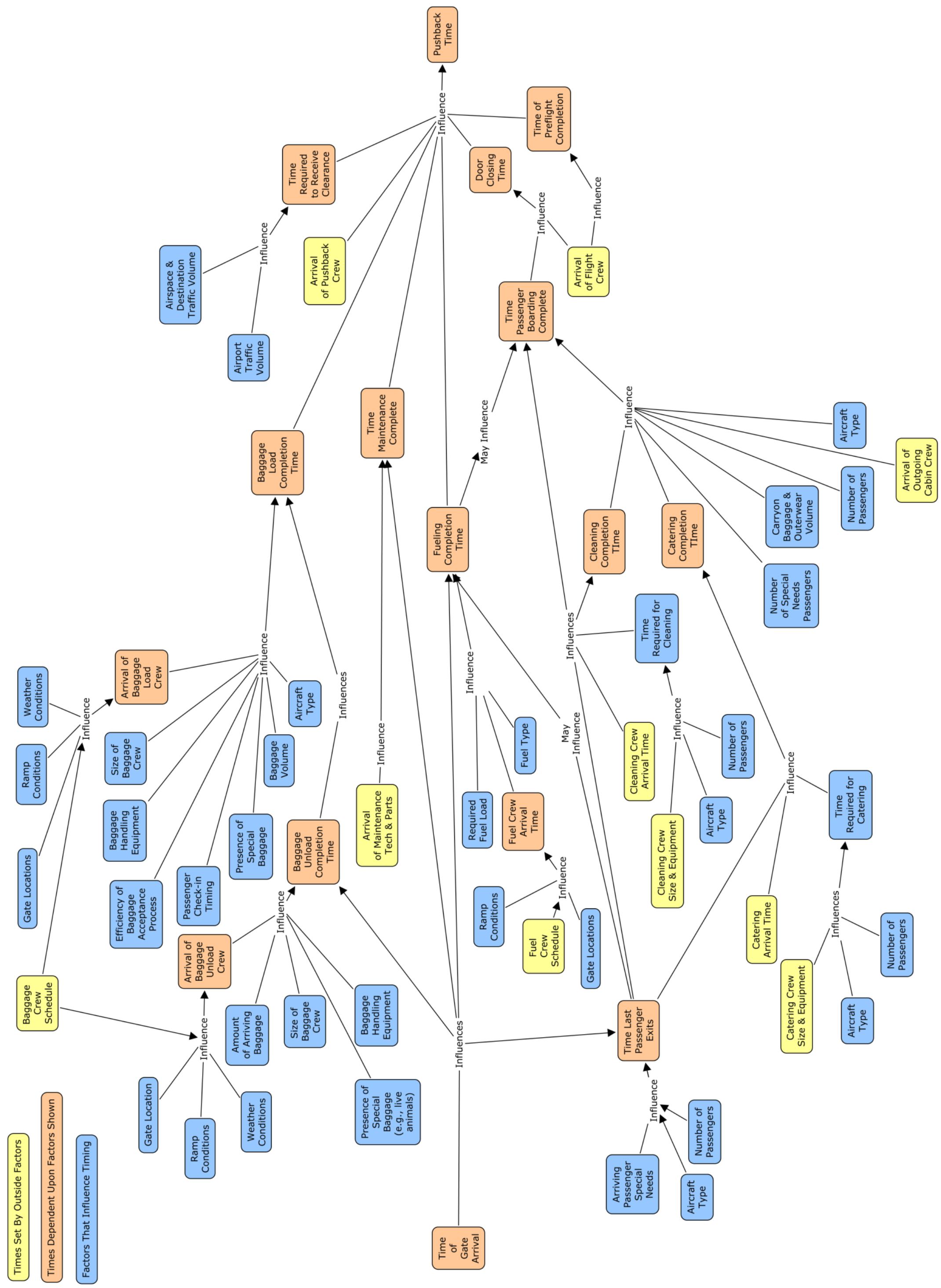

Figure 5. Flow of events for turnaround flights at the gate

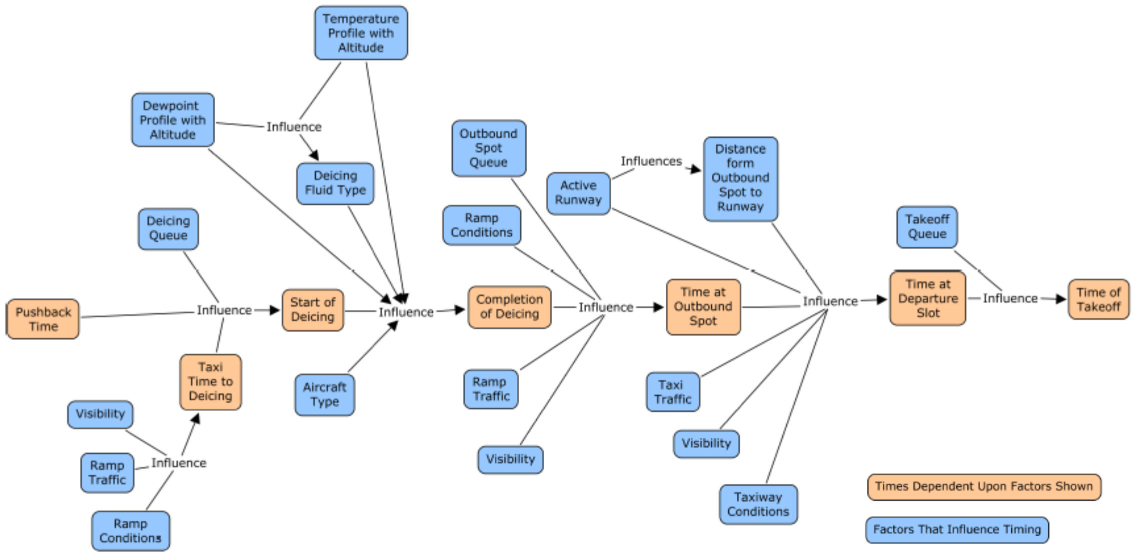

Figure 6. Flow of events for departing flights

Table 1. Independent parameters for Big Data analytics

Phase	Analytics Functions
Arrival	Top of descent to touchdown time=f(aircraft type, equipage, separation distance, wind speed, wind direction)
	Separation distance=f(RVR, equipage)
	Roll out time=f(aircraft type, lwc, snow or rain accumulation rate)
	Landing rate=f(aircraft type, lwc, snow accumulation rate or rain rate)
	Delay at ramp=f(snow accumulation rate or rain rate)
	Dealy at rwy exit=f(aircraft type, lwc, snow accumulation rate or rain rate)
	Taxi speed=f(RVR, lwc, snow accumulation rate or rain rate, separation distance)
	Taxi-in time=f(taxi speed, separation distance, rwy exit, gate assignment)
Gate	Time to unload passenger=f(aircraft type, # passengers)
	Unload baggage delay=f(thunderstorm, lightning, snow accumulation)
	Time to unload_baggage=f(aircraft type, # passengers, # of special need passengers, # of crew, equipment)
	Load baggage delay=f(thunderstorm, lightning, snow accumulation)
	Time to load baggage=f(aircraft type, # passengers, # of crew, equipment)
	Feuling delay=f(thunderstorm, lightning, snow accumulation)
	Time of fueling=f(aircraft type, fuel load)
	Time of cleaning service=f(aircraft type, # of cleaning crew)
	Time of catering=f(# passenger)
	Time of maintenance=f(aircraft type, year, type of issues, facilities)
	Time to board passenger=f(aircraft type, # passengers, # of special need passenger, # gate agent)
	Time to get clearance=f(throughput)
	Time to get to deicing facility=f(taxi_speed, distance to deicing pad)
	Taxi speed=f(RVR, separation distance)
	Time of deicing=f(lwc, snow accumulation rate, aircraft type, type of fluid)
Departure	Taxi out time=f(taxi speed, separation distance, departure rwy, gate assignment)
	Taxi speed=f(RVR, lwc, snow accumulation rate or rain rate, separation distance) Separation distance=f(RVR, lwc, snow accumulation rate or rain rate)
	Take Off Rate=f(lwc, snow accumulation rate or rain rate)

lwc: liquid water content   RVR: restricted visual range   rwy: runway

Table 2. Potential historical data sources

Data	Source	Descriptions	Frequency
ASDI	Ref. 12	Aircraft Situational Display to Industry. Tracks and flight plans in one-minute interval	One-minute
ATCSCC Advisory	Ref. 12	ATC advisories including Ground Delay Program, Airspace Flow Program, Ground Stop, or Reroute	Daily
METAR	Ref. 12	Meterological Aerodrome Reports. Weather information at given airports	Hourly
TAF	Ref. 12	Terminal Aerodrome Forecast. Forecasts of airport weather	6-hr
ARTCC	Ref. 12	Air Route Traffic Control Center. Flight plan and track data from a Cetner computer	Daily
TRACON	Ref. 12	Terminal Radar Approach Control Facility. Flight plan and track data from TRACON computers	Daily
OPSNET	Ref. 12	The Operations Network. Avaiation System Performance Metrics - 77 airports beginning January 1st, 2007.	Monthly
ASPM	FAA	Aviation System Performance Metrics. Scheduled ariport accptance rates (AAR) and actual arrival rates	

IV. The IGTM Prototype

An IGTM prototype[13] was developed to evaluate the modeling and simulation system architecture of the IGTM concept and demonstrate use cases for mitigating off-nominal conditions. Figure 7 shows a fast-time IGTM simulation system architecture using NASA developed Surface Operations Simulator and Scheduler (SOSS)[14] to simulate live arrival and departure traffic as well as surface traffic to and from the gates at the Dallas Fort Worth International Airport. Use cases were developed using the collaborative decision making tools to mitigate the uncertainties associated with early and late arrival of gate operations in meeting the on time pushback performance.

Under this system architecture, the prototype is suitable to support future research and development topics.

1) Evaluate data processing and throughput performance requirements in applying Big Data/Analytics according to volume and type of the data in the IGTM application space.
2) Identify issues in ATM applications associated with developing modeling patterns from historical data.
3) Investigate and evaluate different adaptive analytics methods.
4) Integrate with surface automation tools, such as SARDA, to streamline the on time performance optimization including the gate operations.

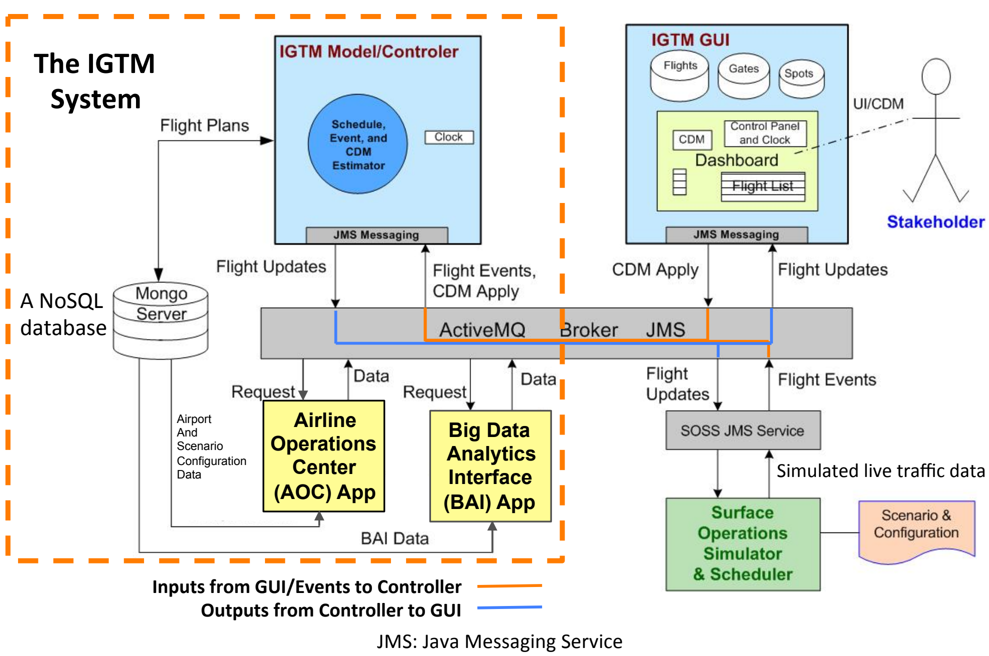

Figure 7. IGTM prototype's system architecture

5) Develop data sharing protocol among stakeholders to ensure integrity, security, and safe use of the data.
6) Develop collaborative decision making tools for mitigating uncertainties to improve the on time performance.

V. Concluding Remarks

An IGTM concept was developed to leverage the potential descriptive, predictive, and prescriptive capabilities as well as adaptively adjust the performance models derived from the Big Data/Analytics to improve the surface and gate management at the airport. The concept also leverages using a distributed communication network to exchange ATC NAS and non-ATC NAS service data to promote the NAS performance optimization across jurisdiction of traffic flow control authorities. Collaborative decision tools are also a key component of the concept to promote total system performance optimization via a local solution through coordination among stakeholders. Finally, a prototype was developed to evaluate the system architecture as well as systems' requirements to support such a concept.

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